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Converter Solutions and Control Methods for Variable Speed Operation of Pumped Storage Power Plants

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At present, the pumped storage hydropower plants are realized with a reversible pump turbine (RPT) and an AC machine (generator/motor) connected to the same shaft. In most of the pumped storage plants, the AC machine is the synchronous machine directly connected to the grid; therefore, the set of machines runs at a constant speed depending upon the frequency of the grid regardless of the amount of water flowing into the turbine/pump. However, it is a well-proven theory that the turbine/pump operates at optimal efficiency only if its speed is varied according to the variation in the water flow. This optimal efficiency operation of hydraulic machines is currently being achieved in several power plants around the world with the help of a Doubly Fed Induction Machine (DFIM) where a frequency converter of approximately 30 % capacity of the stator rating is required to achieve a speed variation of ± 10% of speed. Even though the system is widely used for a few decades, it cannot dynamically switch the operation from generation mode to pumping mode or vice versa which is going to be an important requirement in the near future to balance the increasing amount of renewables being introduced to the grid. Such a dynamic mode switching from turbine to pump and vice versa can only be achieved by decoupling the turbine/generator sets from the AC grid using a full power back-to-back converter between the AC machine and the grid using a converter-fed synchronous machine (CFSM). This technology needs a converter of the same rating as the stator; therefore, the application can be limited by the size of the converter.
In this PhD research, the criteria to select an appropriate full-size converter topology have been presented that can enable the variable speed operation of the existing fixed speed pumped storage plants. In addition, the overall control strategy of the converter and the power plant has been proposed to execute the variable speed operation. The control strategy of the converter and machine was tested in a laboratory prototype of 100 kW capacity with a 2-level back-to-back converter connected between the grid and the synchronous machine. The prime mover of the synchronous machine, which is an RPT in the real application, was emulated using an induction machine. The variable speed operation of the turbine to track the maximum efficiency was simulated using a motor inverter connected to the induction machine.

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Objective

The objective of the research is to address the methods for the selection of full-size converter topology and control of the converters for the variable speed operation of pumped storage plants. The outcome will help determine the size and topology of the converter for the application. In addition, it will also provide a control method for fast startup of the plant in both pump and turbine operation, fast mode transition from the turbine to pump and vice versa, and during low voltage ride through (LVRT) conditions on the grid terminals.

Background

The research in this PhD consists basically of two parts: the converter solution for the application, and the control methods for the converters. The modeling of hydraulics systems and simulation studies have been the basis for finding the requirements of the converters. A set of analytical equations have been derived to determine the loss at different operating points of the possible converter topologies. A detailed evaluation and comparison of the converter topologies have been carried out to determine the method of selection of the converter for this application.
The secondary layer control method for the operation of the pumped storage plant does not rely on the converter topologies. Therefore, the proposed control strategies have been experimentally verified in a laboratory with a two-level three-phase back-to-back converter-fed synchronous machine of 100 kVA. The reversible pump turbine characteristics have been emulated using another set of back-to-back converters.
connected to a squirrel cage induction machine. The control software for the synchronous machine has been developed during this work using Avnet Picozed System-on-Module. The secondary control layer and the emulation of the pumped storage plant components are executed in a MATLAB-based OPAL-RT
real-time simulation system.

Results/Findings

The results show that multilevel converter topologies like NPC, ANPC, and MMC can be suitable for the application. The machine side converter can be NPC or ANPC type as it requires high torque at startup with the runner submerged in water. The grid-side converter can have NPC or MMC topology as it runs at a fixed frequency.
The results also include the following control methods:

1. Start the machine in turbine mode and load it to steady state load via grid side converter
2. Start the machine in pump mode from a standstill with water in the turbine casing and load it to the steady state value
3. Switch the mode of operation from pump to turbine mode without disconnecting from the grid
4. Switch the mode of operation from the turbine to pump mode without disconnecting from the grid

Relevance/utilization

The most relevant application of this project will be the retrofit of the existing fixed-speed pumped storage hydropower projects where the synchronous machine and RPT are already installed. A full-size back-to-back converter would make a better alternative than the combination of a new Induction machine and a smaller converter. In addition, the dynamic transition of the mode of operation from the pump to the turbine and vice versa will enable the power system better to utilize renewable energy sources like wind and solar.

Conclusion

The basic requirements for the converter for such cases are a transformerless connection of the converter to the stator of the machine and to the generator transformer which is around 13–15 kV rms for a machine in the range of 100 MVA, high torque in the low-speed region and provision of a starting torque around 13% at standstill.
The power plants fitted with reversible pump-turbine typically require 13% of rated torque at startup in pump mode. There exist several multilevel converter topologies that can fulfill this requirement. A detailed study of NPC, ANPC, and MMC converter topologies revealed that an NPC converter can provide 30%, ANPC can provide about 60% and MMC can provide about 35% of rated torque at standstill.
with state-of-the-art IGCTs as switching devices. An ANPC converter offers the best performance for starting torque and can be the potential solution for the machine-side converter. Since the grid side converter has an almost constant output frequency, both MMC and NPC converters can be the possible solution.

With a full-size converter, a seamless transition from the turbine to pump mode and vice versa can be executed. This is one of the key advantages if a large power oscillation from the wind and solar plants needs to be regulated using pumped storage plants. The transition time can be less than one minute considering the mechanical time constant of the machine is 12 seconds.

References and links to publications and thesis

https://app.cristin.no/persons/show.jsf?id=911455